Amphibious Tiltrotor for Rescue Operations Subsonic Rotary Wing Project

High School Division
2009-2010 Challenge

Name of School: Yew Chung International Secondary School, Hong Kong

Address of School: [Personal Information Redacted]
Kong SAR, China, Asia

Teacher: CT Leung Email: [Personal Information Redacted]

Student Team Members:

1. Tsz Hin Chung grade 11 Email: [Personal Information Redacted]
2. Mei Kwan Lai grade 11 Email: [Personal Information Redacted]
3. Man Hoi Wong (Nicholas) grade 11 Email: [Personal Information Redacted]

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I. *Main Section*

A. Introduction

All amphibians since 1945 fall easily into two categories: floats and flying boats. We want to change that. With the technology of tiltrotors in our hands, we have designed an unconventional vehicle that bypasses most common design trade offs with marinization.

For the National Aeronautics and Space Administration (NASA) high school level competition: Amphibious Tiltrotor for Rescue Operations Subsonic Rotary Wing Project, we have created a design for an Amphibious Tiltrotor vehicle for civilian rescue missions that meets the following criteria requirements of:

- Can carry up to 50 passengers
- Cruises at 300 knots
- Range of 800 nautical miles

With the capabilities of:

- Land and take off in water or on land
- Siphon water into an internal tank and expel water while airborne

So let's introduce our design: Its name is Fly-Fish.

B. Brief Review of Current Relevant Literature

As Tiltrotor is a fairly new concept, literatures on it are limited. Most were from National Aeronautics and Space Administration (NASA) who piloted the technology with XV-15. On the Internet, the information on tiltrotors was on the most basic details: how it combined fixed wing efficiency and rotor capabilities together. One of our members has a brother in Imperial College London and found in its library: The History of the XV-15 Tiltrotor Research Aircraft from Concept to Flight, by Martin D. Marsel, Demo J. Giulianetti and Daniel C. Dugan. It showed the direction needed to taken to bring the design into civil operation. Namely, safety features, controls, light pilot workload, the need of short takeoff and landing (STOL), need of tackling complex gearing problem, and need of high hover capabilities.

Most relevant literatures were on amphibious designs and rotorcraft designs. Tiltrotor has not yet claimed a section on its own. This was the case in the Central library of Hong Kong, where there were three relevant literature: Wings Over Water A Chronicle of the Flying Boats and Amphibians of the Twentieth Century, By David Oliver, Flying Boats and Amphibians Since 1945, Airlife Publishing Ltd, Jane's Helicopter Markets and Systems Issue 13, edited by Gunter Endres. They provided current systems, technologies and designs on water landing and take off and rotorcrafts.

From the Internet, the most obvious place to look at first was NASA's reference materials: Fundamental Aeronautics Subsonic – Rotary Wing Reference Document, where technical difficulties that were beyond our design requirements were expounded on. Wikipedia was invaluable in finding current technology, systems and designs through gaining an foundation understanding from Wikipedia's articles and then delving deeper by reading the sources cited on Wikipedia and checking its data. Wikipedia was never used as a citation source because of its reliability in question; it was only used as reference. Flight Association websites provide elementary technical knowledge, especially on helicopters. Very specific research on different aspects of aircrafts was focused on in university research papers. They were only useful if the topic was directly related to us. An example was the research paper: The Blended Wing Body Aircraft, by Leifur Leifsson and William Mason. Materials from large organisations like NASA and Bell Helicopters were usually reports and reviews around a program or product. They were especially useful in providing current systems, technologies and designs.

Technical information seemed more accessible through the Internet than printed literature.

C. Discussion of Issues Addressed by the Proposed Design

1. General Issues

Our design will have to tackle many issues to achieve the requirements.

First, to reach the top speed of 300 knots, our design will need to have low drag, powerful engines and increased efficiency for rotors in horizontal flight.

Second, to reach the range requirement of 800 nm, the design will need to have high lift capability and large internal volume to carry fuel.

Third, to carry 50 passengers, our design needs to have high lifting capability and adequate entrance and exits.

Forth, to take off and land on land or water, special fuselage design or floatation device is needed to maintain sea worthiness. It also needs a retractable landing gear for ground landing.

Fifth, to siphon water and release it in flight, special water pump and tank system may be needed. The design also needs high lift capability.

2. Technical Issues with Water Take Off and Landing and Design Tradeoffs of Marinization

a. Sea Worthiness

i. Structural Strength

In order to land on water safely, part of the plane's structure has to be reinforces. In a flying boat design, the belly of the plane will have to support the weight of the craft and absorb the impact of landings, especially in bad weather. In floatplanes, floats will support the plane through series of supportive structure. Additional structures increase weight and floats will induce a lot of drag.

In flying boats, the bow of the plane has to be reinforced and shaped into a hydrodynamic friendly shape so that it will reduce drag and cut through waves without the addition of floats. This results in a design tradeoff causing the plane's shape to be aerodynamically unfriendly.

ii. Stability

The sea, unlike ground, is constantly moving, this will affect the altitude of the plane making take off and landing difficult and dangerous, especially in treacherous weather. To maintain stability, conventional flying boats have a wide boat shape fuselage and small floats are mounted under wing tip in some design. For floatplanes, most design uses multiple floats. Both approach increase drag and weight, reducing payload and speed.

iii. Drag Reduction

For a fixed-wing aircraft to take off from water, the vehicle must have low drag against water. In conventional flying boat, one of the solutions is to add a 'step' under the ship shape fuselage so that it will break the surface of the water and reduce drag as speed of the vehicle picks up. This feature, unfortunately, will also increase drag in air.

b. Tail Clearance

In water take off and landing, tail clearance is a big issue for water take off. Extra tail clearance is needed to prevent a tail strike. Flying boats sit low on water, reducing tail clearance.

c. Corrosion

Corrosion is a big issue for any watercraft. Early flying boats require extensive maintenance on the fuselage to combat corrosion and stay afloat. Corrosion and marine life also increase drag in air and water. To reduce corrosion, paint and galvanization are used. The engines are also vulnerable to corrosion because of repeated contacts with water. So most flying boats use a high wing design to place the engines away from water, this will increase the height of centre of gravity which will reduce stability on water.

D. <u>Design Specification</u>

Requirements:

- Can carry up to 50 passengers
- Cruises at 300 knots
- Range of 800 nautical miles

With the capabilities of:

- Land and take off in water or on land
- Siphon water into an internal tank and expel water while airborne

1. Overview

Fig. 1 An artist's impression of Fly-Fish

To achieve the competition requirements, we came up with a radically new design. Our design is a delta shape-flying wing. It has four engines powering three rotors: one rotor in the front of the vehicle and two rotors behind the vehicle. A helicopter hub controls the front rotor while rear rotors can only swivel forward and backward as if on a kebab stick. Two rotors in the back are synchronized and inter-connected. To counter the toque of the front rotor, a counter toque tail rotor is needed. It will be two ducted fans that are housed inside two horizontal stabilizers. To maintain rotor efficiency, a gearing system will be used. It will reduce rotor speed in forward flight.[1] Three retractable hydrofoils can be deployed for STOL on water. Three retractable floats are used to keep our craft afloat. For landing, we will just use three-point landing gear. Finally our design will have to use computerized fly-by-wire control to maintain flight stability and reduce pilot workload. To reduce storage space, the outboard wing is foldable.

Three View Diagram (Fig. 2.1-2.3):

[1] Martin D. Marsel and Demo J. Giulianetti and Daniel C. Dugan, The History of the V-22 Tiltrotor Research Aircraft from Concept to Flight, National Aeronautics and Space Administration, 2000, page 17.

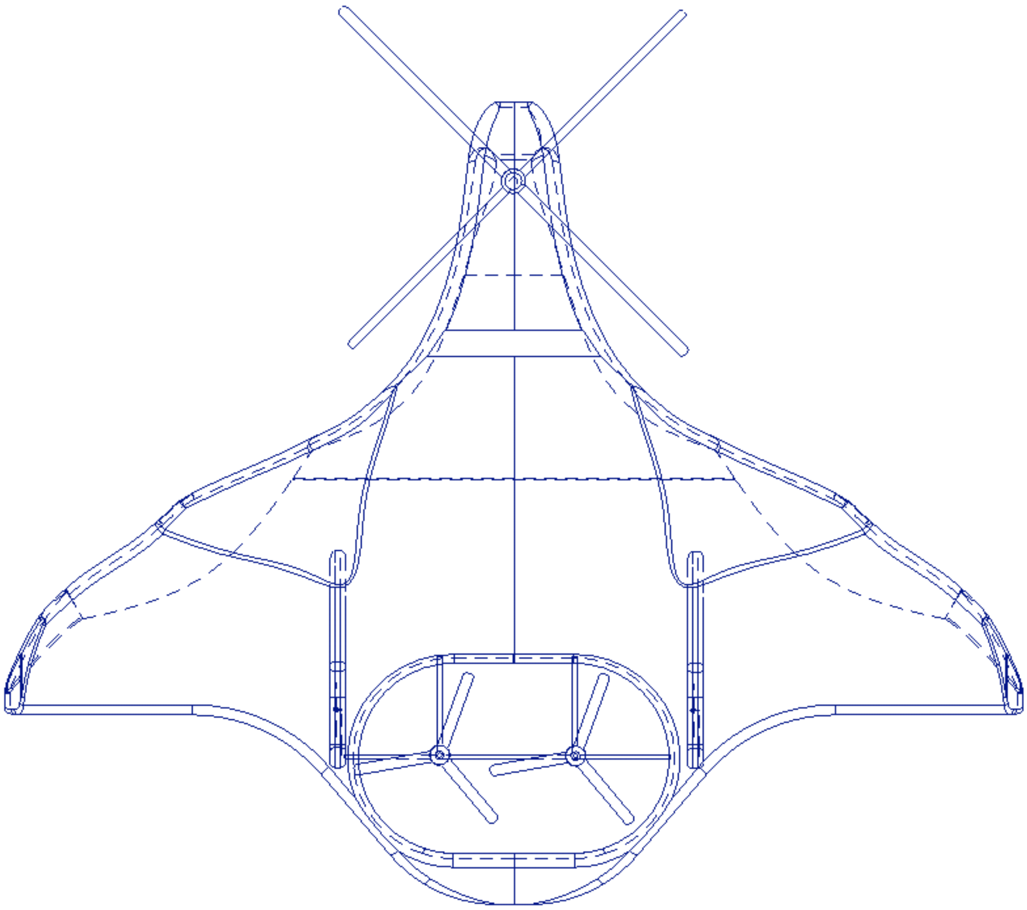

Fig. 2.1 Top view of Fly-Fish

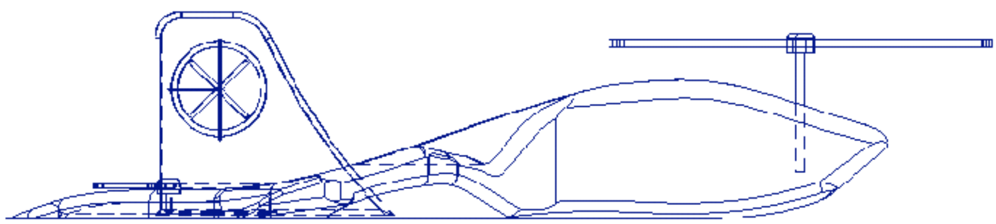

Fig. 2.2 Lateral view of Fly-Fish

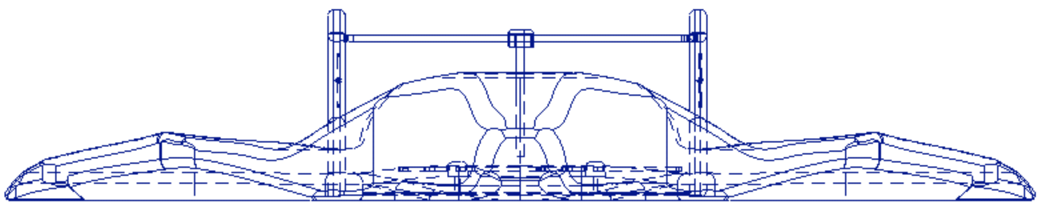

Fig. 2.3 Frontal view of Fly-Fish

2. Main Features

a. Flying Wing Design

Traditional aircraft designs have distinctive wings, fuselage, horizontal and vertical stabilisers, causing a lot of drag. To improve performance, we used a flying wing design in delta shape. Delta shape recoups the lost directional stability. Flying wing has higher internal volume. It has larger allowance for centre of gravity. Flying wing has advantages of aerodynamic efficiency, internal volume and wing area over traditional designs. Therefore a flying wing can carry more, with better fuel efficiency and speed. But it has severe drawbacks in stability. As the B-2 boomer show, large flying wing design is feasible with the aid of computer control. We conclude that a delta shape-flying wing will be prefect for our design.

b. Tri-rotor Design

In our design, there is a big rotor in the front and two small rotors in the back. We use three rotors instead of two rotors because in a delta shape flying-wing design is the best way to place our rotors. The swept angle of the leading edge makes conventional tiltrotor arrangement unusable. We put two rotors in the tail because we cannot fit a full size rotor on the tail. We think the benefits of using a flying wing are greater than the disadvantage of hover stability.

c. Hydrofoil and Floats

To avoid the drawbacks of floatplanes and flying boats, we device a retractable float for our design. Therefore, the floatation device will not produce any drag during flight. The floats have composite skin and a retractable internal frame. The internal frame will force against the skin during extension and pull the skin inwards when retracted. The floats will provide stability during bad weather.

Besides the float, there are also hydrofoils. It will lift the craft off the surface during STOL on water, reducing drag and allowed space for rotation. It will be retractable and lightweight.

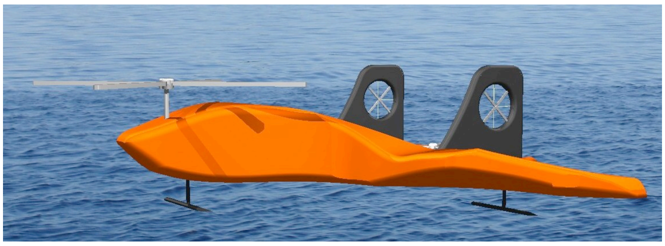

Fig. 3.1 Showing extended hydrofoils

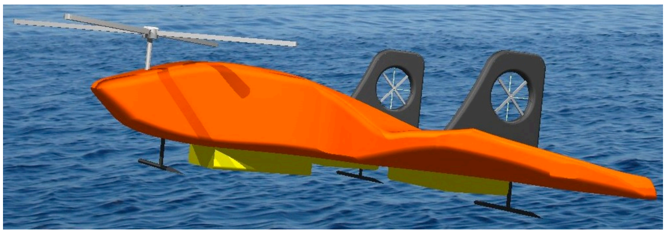

Fig. 3.2 Showing extended hydrofoil and expanded floats

d. Gearing and Interconnection

A gearing system is vital for the development of a tiltrotor. A gearbox is needed to change the engine output into desirable rotor rounds per minute. We would like to use oil free bearing in the gear system to reduce maintenance and increase efficiency.

Two engines behind the craft are interlinked through a cross shaft under the two rotors. We decided not to connect the front and back rotors because it would be too complicated. We rather use two engines to power the front rotor, as two engines will fail at the same time are highly unlikely.

e. Aerial Firefighting Capability

Our design can siphon and release water with minimal modification. Our water siphon and release system contains a scoop, quick install water tanks and a suction pump. When firefighting capability is required, water tanks are installed inside the plane. A retractable scoop located in the forward part of the fuselage and an internal mounted suction pump are connected to the water tanks.

When siphoning water in small water bodies, a pump will bring water into the internal tank via the scoop while the vehicle is hovering. When there is enough space, the vehicle can siphon water by skimming the water surface on hydrofoil. The scoop will be extended to half the height of the hydrofoils and the pump will be turned on to reduce the water pressure on the scoop. This siphoning method will reduce fuel consumption and maintain airspeed. Water will be released through the centre bay door which is located under the belly of the plane.


Fig. 4 Illustration showing scooping mode

3. Modes Configuration

a. Horizontal

Like any tilt rotor, horizontal flight control is identical with common fixed-wing aircraft. In horizontal flight, pilot work load is relatively light, and the auto pilot can be used. In our design, all the control surfaces will be at the back of the plane.

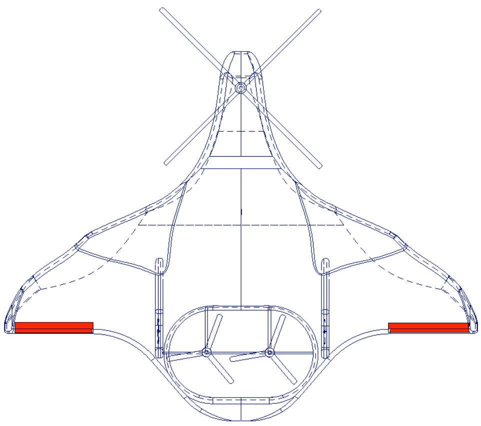
Fig. 5 Showing location of the ailerons


Fig. 6 Showing horizontal flight with the rotors facing forwards

b. Vertical

Our design has similar controls with single rotor helicopter, only that there are two rotors in the back. In yaw, it is controlled by blade pitch of tail rotor like a conventional helicopter. In pitch, it will have differential pitch between front and rear rotors. In roll, it will be controlled by cyclic control and differential collective between two rear rotors.

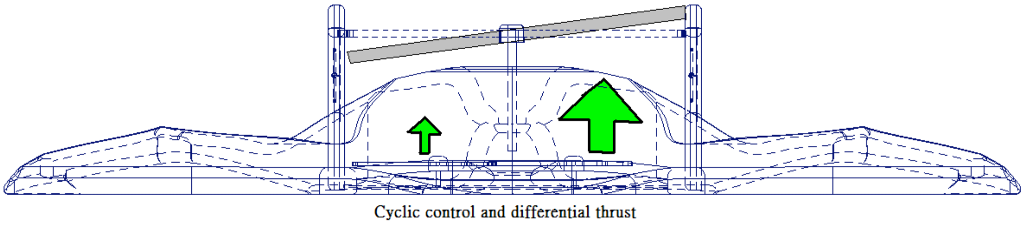

Fig. 7 Showing controls for Roll in rotorcraft mode

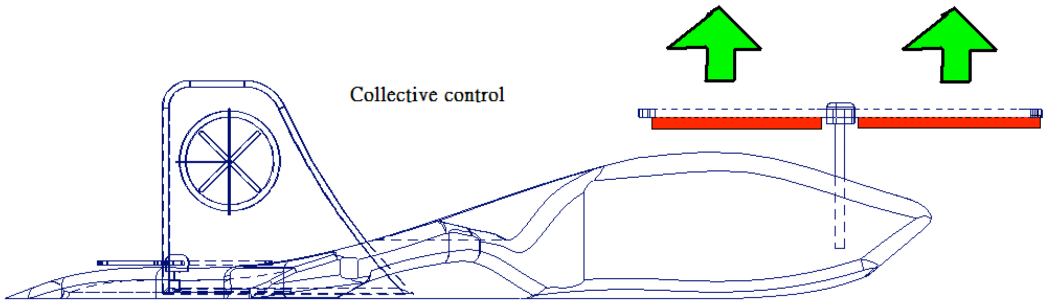

Fig. 8 Showing controls for Pitch in rotorcraft mode

Fig. 9 Showing vertical flight with the rotors facing upwards

c. Water Short Take off and Landing

Landing

- i. approach in fix-wing configuration
- ii. ‘transfer’ rotor to shallow forward bank, maintain steady decent rate
- iii. deploy hydrofoil
- iv. touch down
- v. deploy floats
- vi.f. slow down to a stop

Take Off

- i. set prop tilt to ideal angle
- ii. hydrofoil in effect, lift up body from surface
- iii. retract float
- iv. rotate
- v. clear water surface

d. Land Short Take Off and Landing

The sequence of short landing and take off on the ground is nearly identical to landing on water. The only different is gear, rather than hydrofoil is deployed.

e. Transition

The whole transition will need the aid of an onboard computer. The rotors will tilt forward as the wing slowly gains lift, until it transits to forward flight.

E. Feasibility Analysis - Baseline Comparison with Current systems, Technologies and Designs

1.Firefighting: Seaplanes and Helicopters

a. Comparison with Helicopters

Both Fly-Fish and helicopters can act as aerial firefighting vehicles. They both have capabilities to siphon water in small water bodies. Fly-Fish has similar payload capacity with most medium lift helicopters. Comparing to helitankers, Fly-Fish has a longer range and cruise speed due to its aerodynamic shape and forward facing rotors. Induced drag has been reduced significantly due to the removal of the fuselage and vertical stabilizer. The rotors facing horizontally increase much of the forward thrust. For helicopters, retreating blade stall prevents it from going at high speed. This problem doesn't exist in Fly-Fish. Its longer range and higher cruise speed allow it to stay airborne longer. Fly-Fish also has water-landing capability which is an additional advantage.

b. Comparison with Seaplanes

Both seaplanes and Fly-Fish have water-landing capabilities, however Fly-Fish also has VTOL/STOL capabilities which allow it to siphon water in small water bodies. Fly-Fish has similar efficiency during horizontal flights due to its aerodynamic body and small rear rotors, thus it travels at speed and ranges similar to that of which most seaplanes can achieve. Only the largest seaplanes have the payload and range that can exceed Fly-Fish.

2. Tiltrotor

Comparison Model: Osprey V-22

The largest difference between Fly-Fish and V-22 is the body structure. V-22 uses a conventional straight wing – fuselage. Our design uses a flying wing design. V-22's conventional design allows a pair of rotors that counter rotate each other to be fitted, which eliminate toque and dissymmetry of thrust, therefore becoming more stable than single rotor helicopter in rotor craft configuration. On the other hand, we cannot have the same configuration because of our swept angle. Because our thrust is not symmetrical, our tri-rotor configuration have similar hovering characteristic as single rotor helicopter (also has dissymmetrical thrust), which requires constant flight control input, thus increasing pilot workload.[2] The dissymmetry of thrust presence in our design will induce a lot of problems, such as retreating blade stall.

The back rotors increase chance for tail-strike. During short takeoff and landing (STOL), tail-strike will devastate the aircraft, especially on water. The pilot has to be more careful in watching this aspect. Computer restrictions will slightly relieve this extra workload. The conventional design of V-22 means that its tail can rise far above the ground. The conventional design of V-22 also means that their gearing system is relatively simple. Its system only involves two counter rotating rotors aligning on the longitudinal axis. Our design involves three rotors in two different sizes. Even though the front and rear rotors are not interlinked, two sets of system are still needed. The complex interlinking gearing system in our design poses a challenge for engineers.

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[2] 'C. Gablehouse "Helicopters and Autogiro", 1969' Quoted in Helicopter flight theory. http://www.aviastar.org/theory/index.html, 10 Mar 2010.

Safety features like cross shafting is also easily achievable in V-22 (through the wings). Luckily, our two separate cross shafting systems mean that cross shafting is also easily achievable in Fly-Fish.

Our design is more geared towards horizontal flight efficiency as such will happen quite often in terms of Fly-Fish's function of providing relief to difficult areas. Our flying wing design helps us escape drag problems in conventional fuselage design; Fly-Fish can reach higher speeds than other current designs of tiltrotors because of this. We recouped the lost directional stability with our delta wing shape.

The flying wing design grants us larger internal volume because mathematically, the more a shape is like a sphere, the higher its volume to surface area ratio. For the mission purpose of transporting relief, we have this obvious advantage over V-22.

A huge difference between Fly-Fish and V-22 is that Fly-Fish can have water take off and landing capabilities without using un-aerodynamic designs of protruding floats or boat-shaped hull. This is due to its large, triangular base surface of its flying wing design allowing weight to be spread out stably in a wide tripod shape. Fly-Fish's design submerges shallowly when floating and so a simple hydrofoil design will lift it out of the water.

V-22 is incredibly storage friendly. We have tried to follow so with foldable wings. Though not as compact as a folded V-22, Fly-Fish can be folded while performing vertical takeoff and landing (VTOL) without stunted performance, unlike V-22. Fly-Fish can reach more compact areas this way without jutting wings that take up space.

Our design's mission purpose is for rescue operations: providing relief to difficult areas and finding survivors of a disaster. V-22's mission purpose is diverse: marine vertical assault, air force long-range special operations and long-range combat logistic support are some of the missions planned out for V-22.[3] Our design is more specialized than V-22 and is tailor made to meet the competition requirements.

3. Cost Estimates

Our design will be much more expensive than V-22 which already has 50 million price tag[4]. This is mainly due to the more advance technologies, more complex mechanical systems and more powerful onboard computer. All require costly further research and development. Our design is very unconventional, so previous research is limited. Compare to V-22, a design following XV-15 closely, Fly-Fish, an unconventional design, will cost more.

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[3] Martin D. Marsel and Demo Jo. Giulianetti and Daniel C. Dugan, The History of the V-22 Tiltrotor Research Aircraft from Concept to Flight, National Aeronautics and Space Administration, 2000, page 106

[4] Troshinsky , Lisa, Lean Manufacturing To Cut V-22 Cost, Bell Says, http://www.navair.navy.mil/V-22/?fuseaction=news.detail&id=101, Aerospace Daily & Defense Report , 6 Oct 2004, page 1

F. Requirements Solved

1. Can Carry Up to 50 Passengers
Fly-Fish has relatively large internal volume and heavy lift capability to conventional design as explained previously, therefore carrying 50 people is not very difficult to achieve.

2. Cruise at 300 kts
Our flying wing design has less drag than conventional design of the same size (as explained previously). Fly-Fish is faster than V-22 which has a max cruise speed of 250[5] kts at sea level. With more powerful, oil free engines and gearing system, Fly-Fish should achieve 300 kts without much difficulty.

3. Range 800nm
V-22 have mission radius of 430 nm[1], Fly-Fish has larger internal volume and higher weight lifting capability than V-22, meaning that we can carry more fuel and travel further than V-22. The flying wing design reduces overall drag of our design below that of a conventional design (V-22). With the above improvements, our design can reach a range of 800nm.

4. Land and Take Off in Water or On Land
We devised retractable floats to enable Fly-Fish to float on water safely. We also moved one step further: we added hydrofoil in our design so that it is capable of doing short take off and landings on water. For land landing and take off, we have retractable landing gears that have proven themselves workable many times in other designs. Short take off and landing (STOL) configuration is the same for land except for the choice of landing gears. Vertical take off and landing (VTOL) requires only a small platform that can be landed on and so both land and water are viable candidates. All in all, Fly-Fish can perform both STOL and VTOL on both water and land.

5. Siphon Water into an Internal Tank and Expel Water While Air Borne.
To siphon water for aerial firefighting, Fly-Fish has a water siphon device mounted in the front hydrofoil. When siphoning water in small water body is required, Fly-Fish can siphon water while hovering. Water can be release through the centre bay door located under the belly of the vehicle.

G. Conclusion

1. Summary

Fly-Fish is superior over current tiltrotor designs. With a flying wing design, it carries more, flies faster and achieves longer range. Our design also has amphibious takeoff and landing capabilities; through using retractable float and hydrofoil, the usual design tradeoffs of marinization are avoided. Thus, even with less rotor efficiency, Fly-Fish still has similar, or better performance than most prop-driven, amphibious aircrafts. As all most tiltrotor vehicles, Fly-Fish has vertical takeoff and landing (VTOL), short takeoff and landing (STOL) capabilities, opening access to difficult areas. The abilities to siphon water and expel it are easily implemented into the vehicle. With all these capabilities in mind, our design is well suited to its purpose of rescue operations.

Still, all these superior performance comes with a cost: our design will be demanding for pilots and engineers. The tri-rotor configuration results in higher pilot workload and the complexity of our design will be technologically challenging. So the design will require extensive research and development which we believe is worth it.

2. Recommendations for Further Study - Suggestions for Practical Application/Testing

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[5] V-22 Osprey, http://www.boeing.com/rotorcraft/military/v22/docs/V-22_overview.pdf, Boeing Defense, Space & Security, Feb 2010, page 2

a. Application

Fly-Fish can play a major role in firefighting, search, rescue and transport missions. Tiltrotors are multi-taskers from the beginning because it combines the VTOL capability of helicopter and the speed of fixed wing aircraft, but the water landing capability of Fly-Fish pushes the boundary forward.

It can be very useful in open seas rescue. Fly-Fish can search further than helicopter and still pick up people to safety. It can carry more people than helicopter meaning that it can save more lives.

It can also play a very important role in firefighting, especially in inland regions where large water body is rare. It can travel further for water while having the capability to siphon water in small water bodies.

As a transport, it carries more than any in-service tilt rotor. It can reach beyond the range of helicopters and land on places where fixed wings cannot. So when natural disasters strike, when airports and other means of transportation are destroyed, Fly-Fish can react faster and carry more supply than any other vehicles.

b. Testing

Fly-Fish uses many new technologies and it is a radical design. Therefore extensive testing and research must be done before it enters into production. During the design stage, testing and research should be done on individual components, especially on rotors, engine and transmission, because these are the most technically demanding parts. Wind tunnel test should be done on scale model, to test for the aerodynamic property of our design. This test will prevent costly mistakes during prototype stage. Computer modeling will also be a very important tool for the design. Once the prototype is done, the main focus will be on flight testing. Tests could be on the flight envelope, safety and practicality of the vehicle. Other tests can also be done, such as acoustic test and stress test.

II. *Other Required Material*

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B. Scanned Letter from Teacher

Original Work Affirmation Letter

I, the supervising adult of Chung Tsz Hin, Lai Mei Kwan and Nicholas Wong, certify that the written work in this project are their own original work.

Signed: ______________________________

C T Leung (Physics Teacher)

Yew Chung International School – Secondary

Date: March 15, 2010